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MEMORANDUM REPORT No. 929

The Aerodynamic Properties Of The 105mm HE Shell, M1, In Subsonic And Transonic Flight

EUGENE T. ROECKER

DEPARTMENT OF THE ARMY PROJECT No. 5B0305005
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0230

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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MEMORANDUM REPORT NO. 929

ETRoecker/mlu
Aberdeen Proving Ground, Md.
September 1955

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ABSTRACT

The aerodynamic properties of the 105mm HE shell, M1, at subsonic and transonic speeds are presented and discussed. These properties were determined by full scale tests in the Transonic Spark Range. Particular attention is given to non-linearities with yaw of some of the aerodynamic coefficients of this shell and to the dynamic stability of the shell as a function of Mach number and yaw. The results show that the effect of these non-linearities is to compel the shell to travel at constant yaw of about three degrees for subsonic velocities. Comparison with long range, time-of-flight firings neither verified nor refuted this prediction.

TABLE OF SYMBOLS

A	axial moment of inertia	lb - in^2
B	transverse moment of inertia	lb - in^2
C.M.	center of gravity measured from the nose	calibers
CP_N	center of pressure of normal force	calibers
d	bourrelet diameter	in (cal)
$\overline{\delta^2}$	mean squared yaw	(deg)^2
ϵ_i	absolute standard error in a coefficient	
$\%\epsilon_i$	per cent standard error in a coefficient	
$\|K_1\|$	magnitude of nutational yaw vector	rad
$\|K_2\|$	magnitude of precessional yaw vector	rad
$K_D = \frac{\pi}{8} C_D$	drag force coefficient	
K_{D_o}	zero-yaw drag force coefficient	
$K_{D_{\overline{\delta^2}}}$	yaw drag force coefficient	(rad)$^{-2}$
$K_H = -\frac{\pi}{16}(C_{M_q} + C_{M_{\dot{\alpha}}})$	yaw damping moment coefficient	
$K_L = -\frac{\pi}{8} C_{L_\alpha}$	lift force coefficient	
$K_M = \frac{\pi}{8} C_{M_\alpha}$	overturning moment coefficient	
$K_N = -\frac{\pi}{8} C_{N_\alpha}$	normal force coefficient	
$K_T = -\frac{\pi}{16} C_{M_{p\alpha}}$	Magnus moment coefficient	
ℓ	length of shell	in (cal)
λ_1	nutational yaw damping rate	(ft)$^{-1}$
λ_2	precessional yaw damping rate	(ft)$^{-1}$
M	Mach number	
m	weight of shell	lb

TABLE OF SYMBOLS

N	number of yaw stations	
N_T	number of timing stations	
$(R_2)_L$	radius of swerve	ft
s	gyroscopic stability factor	
$\bar{s}$	dynamic stability factor	

I. INTRODUCTION

Recently the Exterior Ballistics Laboratory was engaged in an investigation of the aerodynamic characteristics of two developmental shell: the 110mm T194 and its modifications* and a 4.9 caliber long, square based shell.[1] It was found that these shell exhibited dynamic instability in a narrow band of Mach numbers near the speed of sound. Since these shell, except for being slightly longer than ordinary, had conventional configurations, the question naturally arose whether some of the standard, well-known shell exhibited this feature also. Hence, the 105mm Howitzer shell, HE, M1, (which is somewhat similar to these developmental shell) was selected for a program of firings at transonic and subsonic velocities through the Transonic Range[3]. This report contains the results of those firings.

The 105mm shell, HE, M1, is approximately 4.7 calibers in overall length; it has a 0.5 caliber, 9° conical boattail (Appendix C). Preliminary firings showed that "normal" yaws acquired in the launching of this shell were unsatisfactorily small for study of its aerodynamic characteristics. To increase the yaw, the shell's bourrelet diameter was undercut by .030 inches. Forty-two undercut rounds, covering a Mach number range from 0.48 to 1.22, were fired for this program through the Transonic Range from a 105mm Howitzer tube (1/20 twist) mounted on an M7 motor carriage.

Investigation of the data from these 42 rounds showed variations of the yaw damping rates with yaw. In particular, at subsonic velocities, the shell appeared to be dynamically unstable at small yaws and stable at yaws larger than about three degrees. Hence, eleven additional rounds were fired subsonically without undercutting to verify whether these observed variations for the undercut shell would hold true for the unmodified shell. Necessarily, the yawing motions of these eleven rounds were relatively small.

The observed variations with yaw of the dynamic coefficients for the 42 undercut shell did hold true for the unmodified shell. However, comparison of the K_M values between the undercut and unmodified shell revealed

* Unpublished data

sizable differences. Further investigation showed that these differences were not due to undercutting per se. Unfortunately two different fuzes (M73 and M51A5) were used for this program, and it is not known which round had which fuze. However, the 42 undercut rounds appear to have had the M51A5 fuze whereas most of the eleven unmodified rounds appear to have had the M73 fuze.

Table I has the physical measurements of sample shell. Part A has the data used in handling the 42 undercut rounds; part B, the eleven unmodified rounds. Parts C and D, respectively, are recent measurements of shell with M73 and M51A5 fuzes. In particular, the variation of the transverse moment of inertia between both types and the shift in center of mass position accounts for the observed scatter in the K_M data.

Moreover, the aerodynamic coefficients for the undercut rounds were computed using the undercut diameter (4.095 inches) instead of the unmodified diameter (4.126 inches). Consequently, the coefficients for the undercut shell are slightly larger than the coefficients for the unmodified shell.

II. DATA

The reduction of firing data to extract aerodynamic information is described fully in Reference 4. The final output of this process is the aerodymanic coefficients of forces and moments as functions of Mach number and yaw. The yaw level of each round is conveniently expressed as mean squared yaw over the observed trajectory.

In this program the precessional and nutational arms were about the same size at mid-range. Since the quality of the data depends on the number of stations of observation and the level of yaw (relative to the error in yaw measurement), the following criteria have been used in retaining the data:

Quantity	Criteria	No. of Rds. Which Satisfy Criteria	
		Undercut	Unmodified
K_D	$N_T > 5$	42	11
K_M, s	$\lvert K_1 \rvert > .008$ $\% \epsilon_{K_M} < 4\%$	36	6
K_L	$(R_2)_L > .04$ ft	20	5
CP_N	satisfactory K_L and K_M	20	5
λ_1, λ_2, K_H, K_T	$\lvert K_1 \rvert > .013$	32	5
$\bar{s}$	satisfactory K_L, K_H and K_T	20	5

$N > 13$ for all rounds except Rd. No. 1960 for which only K_D is tabulated.

A. Drag Coefficient

Graph 1 plots K_{D_o} vs M. Since there appeared to be little or no variation of K_{D_o} with Mach number between M = .48 and M = .85, a least squares fit of the equation:

$$K_D = K_{D_o} + K_{D_{\overline{\delta^2}}} \overline{\delta^2},$$ where $\overline{\delta^2}$ is in square radians, for the rounds fired in this subsonic interval, resulted in:

$$K_{D_o} = .0477 \pm .0005$$

$$K_{D_{\overline{\delta^2}}} = 2.4 \pm .2$$

Above M = 1.1, $K_{D_{\overline{\delta^2}}}$ appeared to be about 4.3.

It can be seen in Graph 1 that the unmodified rounds apparently have lower K_{D_o} values subsonically. However, as explained in the Introduction, this is due to using different diameters in computation. The diameter for the undercut shell was 4.095 inches; for the unmodified shell, 4.126 inches.

B. Lift and Overturning Moment Coefficients

K_M vs M is given in Graph 2 and K_L vs M in Graph 3. The K_L vs M curve peaks sharply at around M = 1. To facilitate the construction of this curve in the transonic region, a special swerve reduction, which allows K_L to vary with M, producing a dK_L/dM value, was used for rounds fired at transonic velocities. The K_L values obtained for these rounds by this special swerve reduction did not change significantly from those values previously obtained by the usual constant coefficient swerve reductions. However, the slope parameters were an aid in constructing the variation of K_L with M in the transonic region.

Table I shows that the shell with the M73 fuze has a 4% larger transverse moment of inertia than has the shell with the M51A5 fuze. Consequently, if a shell with an M51A5 fuze were fired and had its K_M value computed by using measurements taken of a shell with a M73 fuze, the difference between the transverse moments of inertia of the two types, would result in an observed K_M value 4% greater than its actual K_M value. In addition, the c.m. position of the shell with the M73 fuze is about .02 caliber forward of the c.m. position of the shell with the M51A5 fuze. Since the distance between the center of pressure of the normal force and the center of mass is on the order of 2 calibers, the farther rearward c.m. position of the shell with the M51A5 fuze results in a 1% larger K_M value for that shell. Therefore, it would seem that the higher K_M values of the unmodified shell can be primarily attributed to the above differences.

CP_N vs M is plotted in Graph 4. The most forward position of CP_N occurs at M = .94. This position is approximately at the nose of the shell.

C. Yaw Damping Rates

The linearized theory(5) of yawing motion was used in the reduction of the firings in this program. This theory postulates that for small yaws the aerodynamic coefficients K_M, K_L, K_H, and K_T are constant with yaw and with Mach number over the length of trajectories involved in measurement. In the analysis of the data in this program it became evident that the dynamic coefficients K_H and K_T and, consequently, the damping rates λ_1 and λ_2 had a marked dependence on yaw even though the yaws obtained were small. Hence, the values obtained for these coefficients by a reduction based on a linearized theory of yawing motion cannot strictly be considered as the actual values of the aerodynamic coefficients. But, the variations with yaw of these dynamic coefficients can be observed between rounds of different yaw levels. Graphs 5 through 11 are so drawn as to enable the reader to observe these variations.

For subsonic velocities, Graph 5 plots λ_1 and λ_2 vs mean squared yaw, $\overline{\delta^2}$, since no variation of λ_1 and λ_2 with Mach number was apparent in the region $.48 < M < .81$. Graph 5 offers evidence that for small mean yaws the precessional yaw vector will grow.

With the aid of Graph 5, Graphs 6 and 7 plot λ_1 and λ_2, respectively, vs Mach number for different mean squared yaw levels. In the transonic region the damping rates vary markedly with Mach number as well as with yaw. Since it was impossible to separate the dependence of the damping rates on yaw in the transonic region from their dependence on Mach number, the extensions of the subsonic yaw levels into the transonic region can be offered only as mere indications of possible trends.

D. Damping Moment Coefficient

From Graph 5 it can be seen that, when $\overline{\delta^2} > 3$ square degrees, the sum of the two curves, i.e., $(\lambda_1 + \lambda_2)$ vs $\overline{\delta^2}$, is a horizontal line with $(\lambda_1 + \lambda_2) \cong .45 \times 10^{-3}\ (\text{ft})^{-1}$. Now, K_H is computed as a function of $(\lambda_1 + \lambda_2)$ and K_L. But, K_L did not appear to vary with yaw subsonically.

Hence, K_H does not vary with yaw subsonically when $\overline{\delta^2} > 3$ square degrees as can be seen in the K_H vs M curve plotted in Graph 8. For $\overline{\delta^2} < 3$ square degrees, the shell has a relatively larger K_H, subsonically.

In the transonic region, K_H varies both with Mach number and with yaw, smaller yaw producing a relatively larger K_H.

E. Magnus Moment Coefficient

Graph 9 plots K_T vs $\overline{\delta^2}$ for the region $.48 < M < .81$. With the aid of Graph 9, K_T vs M is plotted in Graph 10 for different mean squared yaw levels. Subsonically, K_T is positive with smaller yaw producing a relatively larger K_T. For $M > 0.9$, K_T is negative and appears to depend primarily on Mach number rather than yaw.

F. Dynamic Stability

From Table 3 it can be seen that the gyroscopic stability factor, s, of the shell ranges from 2 to 3. The shell is amply stable gyroscopically. The dynamic stability factor, $\bar{s}$,* of the shell is plotted vs Mach number for different mean squared yaw levels in Graph 11. For transonic and supersonic velocities the shell is dynamically stable for all levels of yaw measured. In subsonic flight, however, it was seen that the shell is dynamically unstable (increasing precessional yaw) for very small yaws. From Graph 11 it can be seen that $\bar{s}$ is negative for subsonic Mach numbers and for an angle of yaw less than some critical angle of about three degrees. Hence, not only is the shell dynamically unstable subsonically for yaw less three degrees, but imparting greater spin will not remedy this situation.

III. CONCLUSIONS

Investigation into the aerodynamic characteristics of certain shell (mentioned in the Introduction) led to the firing of the program in this report in order to discover whether the M1 shell, in spite of its overall satisfactory behavior, might exhibit dynamic instability at certain speeds. The results show that the shell is dynamically unstable subsonically at small yaws. This instability arises from fairly large positive values of the Magnus moment coefficient. However, the shell recovers its dynamic stability at yaws greater than three degrees; hence, the overall behavior of the shell is satisfactory.

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* $\bar{s} < 0$ or $\bar{s} > 2$ implies that the shell is dynamically unstable and cannot be stabilized by resorting to higher spins (Reference 2).

The findings seem to indicate that after a sufficient amount of travel in subsonic flight, the magnitude of the yaw of the 105mm M1 shell should be virtually non-oscillatory at about three degrees. In such a case, the expected K_D would not equal K_{D_O} but would also include the necessary increment due to yaw, i.e., about 10% increase in drag. A search for such evidence in the present firing tables of the shell revealed nothing conclusive.

It was found from the Firing Records that the mean of the times of flight for 22 rounds fired at an average muzzle velocity of 884.6 ft/sec at an elevation angle of $45^{\circ}1'$ was 36.8 seconds with a standard deviation of 0.2 second for a range of 6539 yards. Using the same initial conditions and the same range, the time of flight for a zero-yaw trajectory (K_{D_O} = .0477) should be 36.5 seconds. The unmodified rounds in this report show an average first yaw maximum of 1.9 degrees or a mean squared yaw of two squared degrees at the muzzle. Using this yaw level as an initial condition and applying the dynamic properties as determined in this report, i.e., the shell will reach an equilibrium yaw of 3 square degrees, the time of flight to 6539 yards is 37.3 seconds.* The difference between these predicted times of flight is not large enough, relative to the standard deviation of 0.2 second obtained for the measured times of flight, to either verify or refute the dynamic predictions of this report.

Eugene T. Roecker

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* In firings where large angles of elevation are used, yaws (or additional yaws) occur near the summit. The dynamic properties of this report predict that the shell will reach three degrees circular yaw long before the summit. Consequently, near the summit the yaw may increase to about six degrees. According to the dynamic properties, this six degrees of yaw should decrease to three degrees in about 1000 yards. The resulting increase in time of flight, due to the additional three degrees of yaw at the summit, would be about 0.1 second.

IV. APPENDICES

APPENDIX A: TABLES OF DATA

TABLE 1

Average Physical Measurements

105MM M1

	Shell	m (lb.)	A (lb - in^2)	B (lb - in^2)	d (in.)	ℓ (in.)	C.M. (in. from base)
A.	undercut	32.92	79.13	741.8	4.095	19.365	7.11
B.	unmodified	33.06	79.5	773	4.126	19.412	7.22
C.	with M73 fuze	33.0	79.39	781.4	4.127	19.419	7.193
D.	with M51A5 fuze	33.0	79.70	752.0	4.129	19.394	7.114

TABLE 2

Aerodynamic Coefficients

105MM M1

Rd. No.	M	$\overline{\delta^2}(\text{deg})^2$	K_D	K_M	K_L	CP_N (calibers from nose)	K_H	K_T
1964	.479	.7	.0490	--	--	--	--	--
1963	.480	4.8	.0516	1.43	.57	.70	- .4	.29
1432	.496	23.4	.0638	1.44	.63	.91	1.7	-.02
1431	.505	21.9	.0630	1.44	.62	.90	1.1	.03
1962	.530	2.6	.0525	--	--	--	--	--
1430	.546	3.0	.0504	1.48	--	--	3.8*	.10*
1961	.550	6.2	.0533	1.43	.60	.82	3.8	.01
1959	.584	4.0	.0496	1.47	.67	.97	1.3	.20
1960	.591	7.7	.0534	1.47	.68	1.00	.5	.14
1359	.607	13.8	.0588	1.42	.72	1.17	1.4	.02
1958	.623	2.1	.0490	1.52	--	--	--	--
1957	.623	2.1	.0483	1.51	--	--	4.7*	.17*
1358	.634	7.9	.0565	1.49	.65	.90	1.7	.08
1955	.672	4.9	.0562	1.49	.61	.78	2.1	.08
1956	.680	2.3	.0476	--	--	--	4.6*	.17*
1357	.684	4.9	.0542	1.51	.53	.42	2.1	.10
1356	.716	1.3	.0499	--	--	--	--	--
1321	.745	20.3	.0610	1.54	.61	.70	1.8	-.03
1314	.808	13.1	.0576	1.54	.60	.64	1.1	.07
1485	.862	.8	.0512	--	--	--	--	--
1474	.864	3.5	.0496	1.58	--	--	4.4*	-.05*
1476	.865	1.0	.0487	1.63	--	--	--	--
1475	.867	2.4	.0501	1.60	--	--	4.6*	.21*
1477	.869	4.6	.0516	1.59	--	--	4.5*	-.11*
1478	.870	2.8	.0522	1.59	--	--	5.2*	-.05*
1481	.879	2.7	.0475	1.58	--	--	4.5*	.07*
1482	.886	2.0	.0509	1.52	--	--	4.4*	.08*
1319	.901	11.7	.0646	1.72	.56	.22	3.0	-.10
1310	.915	20.8	.0678	1.68	.54	.23	2.9	-.16
1309	.928	3.8	.0666	1.77	--	--	6.3*	-.17*
1313	.941	9.9	.0743	1.80	--	--	3.2*	-.25*
1300	.944	2.0	.0696	1.87	--	--	--	--
1320	.944	.8	.0784	1.97	--	--	--	--
1308	.963	3.5	.0880	1.74	--	--	6.3*	-.19*

* K_L estimated from Graph 3.

TABLE 2 (CONT'D)

Rd. No.	M	$\overline{\delta^2}(deg)^2$	K_D	K_M	K_L	CP_N (calibers from nose)	K_H	K_T
1299	.970	1.1	.0901	--	--	--	--	--
1298	.970	1.3	.0852	1.72	--	--	--	--
1307	.989	11.7	.1303	1.69	.81	1.20	4.4	-.18
1306	1.018	7.7	.1595	1.60	.71	1.16	4.8	-.18
1315	1.051	8.7	.1655	1.56	.62	.99	3.7	-.11
1316	1.112	8.7	.1734	1.54	.65	1.12	3.2	-.07
1317	1.164	5.3	.1667	1.57	.69	1.16	3.6	-.07
1318	1.221	15.1	.1725	1.56	.74	1.28	4.0	-.06
3191**	.790	1.7	.0488	1.68	.70	.71	2.9	.14
3192	.762	.4	.0466	--	--	--	--	--
3193	.693	.3	.0469	--	--	--	--	--
3194	.701	.6	.0458	--	--	--	--	--
3196	.787	1.1	.0459	1.56	--	--	--	--
3197	.813	1.4	.0455	--	--	--	--	--
3199	.642	4.4	.0503	1.55	.73	.97	3.7	.06
3202	.519	3.6	.0504	1.49	.71	.99	2.4	.14
3203	.627	2.2	.0473	1.61	.62	.56	3.0	.26
3204	.828	1.0	.0467	--	--	--	--	--
3206	.847	2.5	.0496	1.65	.54	.14	4.2	-.02

Average Standard Error

ϵ_{K_D}	ϵ_{K_M}	ϵ_{K_L}	ϵ_{K_H}	ϵ_{K_T}
.0004	.01	.03	.6	.04

** Rounds 3191 - 3206 have not been undercut.

TABLE 3

Yaw and Swerve Data

105MM M1

Rd. No.	K_1 (rad)	K_2 (rad)	$(R_2)_L$ (ft)	s	$\bar{s}$	$\lambda_1 \times 10^3$ $(ft)^{-1}$	$\lambda_2 \times 10^3$ $(ft)^{-1}$	N	N_T
1964	.007	.012	.01	--	--	--	--	19	6
1963	.021	.031	.05	2.59	-12.	.59	-.52	19	6
1432	.060	.059	.11	2.96	.83	.32	.18	19	9
1431	.064	.051	.10	2.98	.59	.29	.08	19	6
1962	.012	.020	.03	- --	--	--	--	19	10
1430	.021	.021	.03	2.75	--	.87	-.17	20	9
1961	.028	.032	.06	2.58	.31	.91	.07	19	7
1959	.017	.030	.05	2.50	-.91	.79	-.33	19	9
1960	.027	.040	.07	2.53	-.58	.43	-.14	24	10
1359	.052	.041	.08	2.74	.67	.34	.14	25	8
1958	.010	.022	.03	2.44	--	--	--	22	8
1957	.013	.021	.03	2.44	--	1.55	-.31	23	7
1358	.031	.038	.07	2.77	.10	.54	-.04	25	8
1955	.022	.031	.05	2.48	.05	.68	-.07	23	7
1956	.024	.019	.03	2.42	--	1.53	-.39	21	7
1357	.021	.032	.05	2.74	-.16	.67	-.12	22	9
1356	.011	.016	.02	--	--	--	--	10	5
1321	.057	.054	.09	2.74	.86	.30	.22	18	9
1314	.043	.047	.07	2.62	.16	.38	-.01	19	8
1485	.008	.013	.01	--	--	--	--	22	10
1474	.024	.023	.03	2.69	--	.81	.18	20	8
1476	.011	.013	.02	2.56	--	--	--	20	6
1475	.018	.020	.03	2.69	--	1.47	-.43	19	8
1477	.029	.026	.03	2.68	--	.72	.32	19	8
1478	.018	.023	.03	2.70	--	1.01	.15	20	9
1481	.017	.023	.02	2.54	--	1.19	-.11	24	7
1482	.016	.018	.02	2.57	--	1.18	-.13	24	7
1319	.043	.041	.04	2.25	.91	.43	.32	20	10
1310	.063	.048	.05	2.34	1.24	.24	.46	21	10
1309	.025	.023	.01	2.18	--	.99	.38	22	10
1313	.044	.033	.03	2.19	--	.09	.69	21	10
1300	.012	.019	.02	2.04	--	--	--	24	10
1320	.011	.011	.01	2.05	--	--	--	18	10
1308	.022	.023	.03	2.30	--	.96	.44	22	10
1299	.007	.015	.01	--	--	--	--	24	11
1298	.010	.016	.02	2.19	--	--	--	21	7
1307	.043	.040	.07	2.57	1.02	.53	.57	24	10
1306	.035	.032	.05	2.58	.93	.64	.51	22	9

TABLE 3 (CONT'D)

Rd. No.	K_1 (rad)	K_2 (rad)	$(R_2)_L$ (ft)	s	$\bar{s}$	$\lambda_1 \times 10^3$ $(ft)^{-1}$	$\lambda_2 \times 10^3$ $(ft)^{-1}$	N	N_T
1315	.035	.037	.05	2.62	.83	.55	.36	22	10
1316	.035	.037	.06	2.71	.76	.54	.28	21	10
1317	.025	.031	.05	2.68	.71	.64	.29	15	7
1318	.046	.049	.09	2.69	.63	.58	.31	15	8
3191**	.015	.016	.05	2.58	-.19	.94	-.19	16	9
3192	.005	.010	.01	--	--	--	--	22	11
3193	.009	.005	.03	--	--	--	--	19	9
3194	.007	.011	.02	--	--	--	--	15	8
3196	.012	.013	.02	2.46	--	--	--	20	11
3197	.000	.021	.01	--	--	--	--	21	10
3199	.029	.020	.06	2.73	.19	.94	-.01	20	10
3202	.018	.027	.08	2.71	-.22	.83	-.18	13	9
3203	.015	.020	.05	2.65	-.86	1.28	-.51	20	12
3204	.005	.017	.03	--	--	--	--	20	10
3206	.014	.023	.04	2.52	.39	.92	.09	19	12

Average Yawing Rates

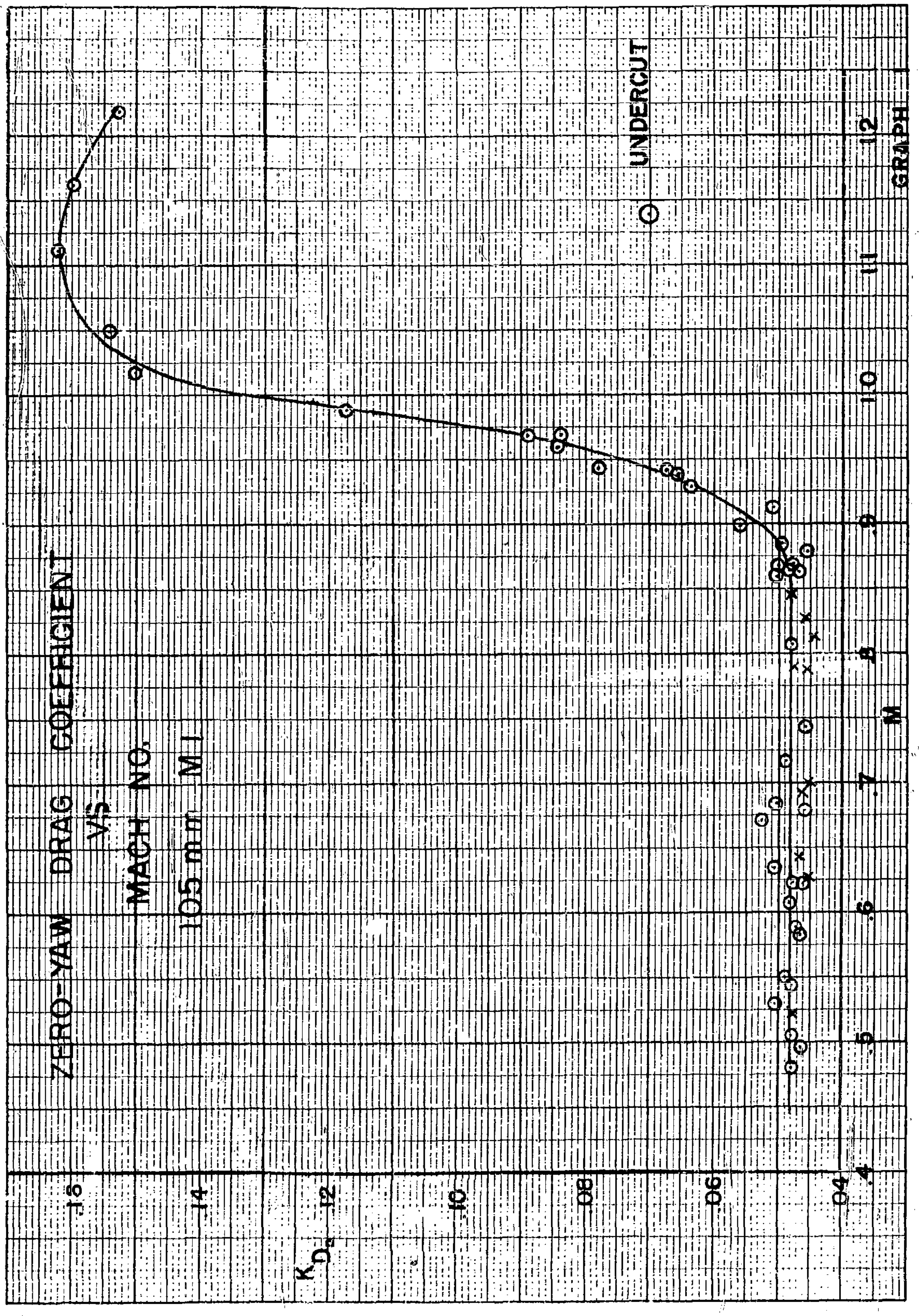
b_1	b_2
4.95 deg/ft	.62 deg/ft

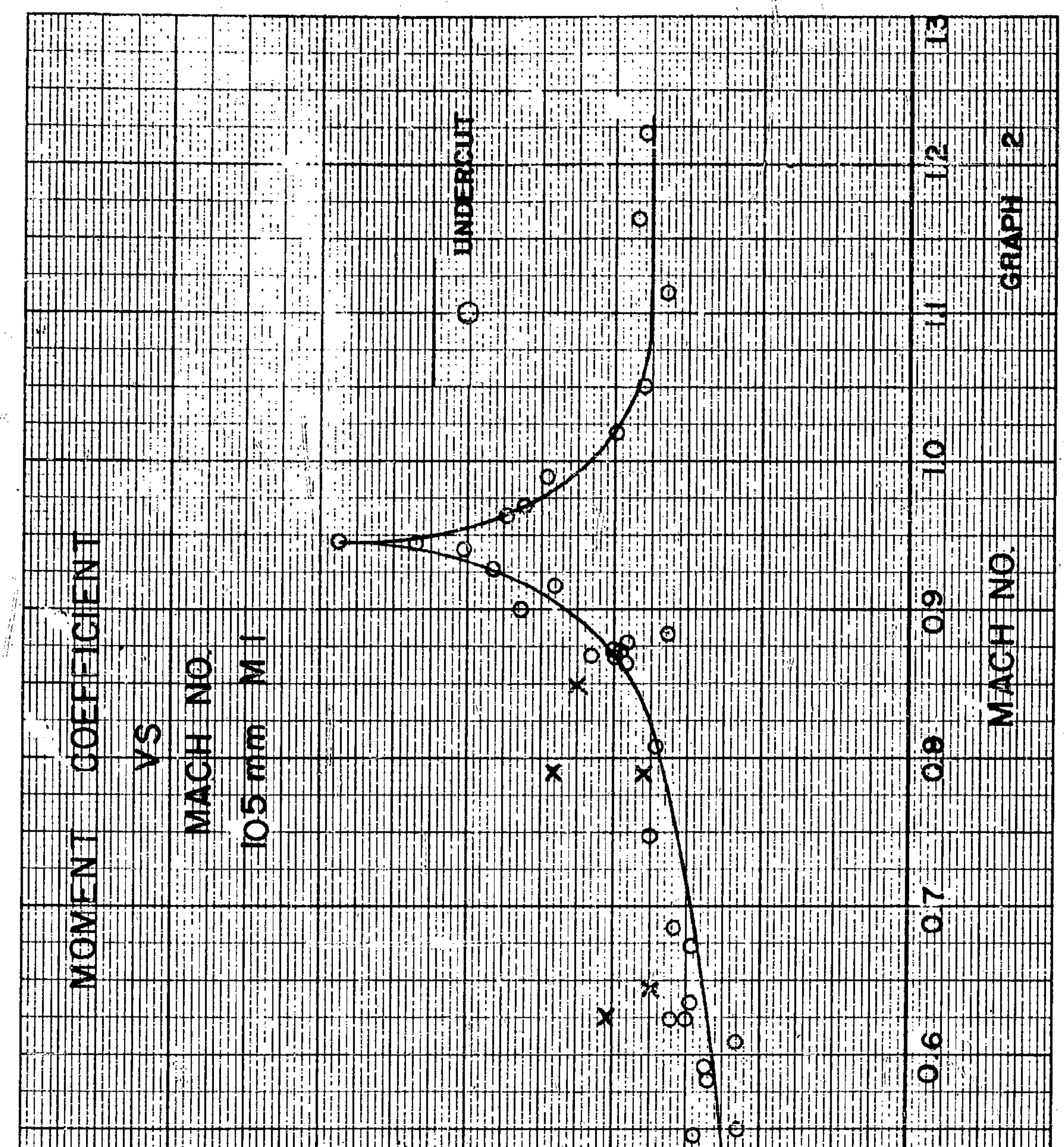
Average Standard Error

$\epsilon_{\lambda_1} \times 10^3$	$\epsilon_{\lambda_2} \times 10^3$
.09 $(ft)^{-1}$	.08 $(ft)^{-1}$

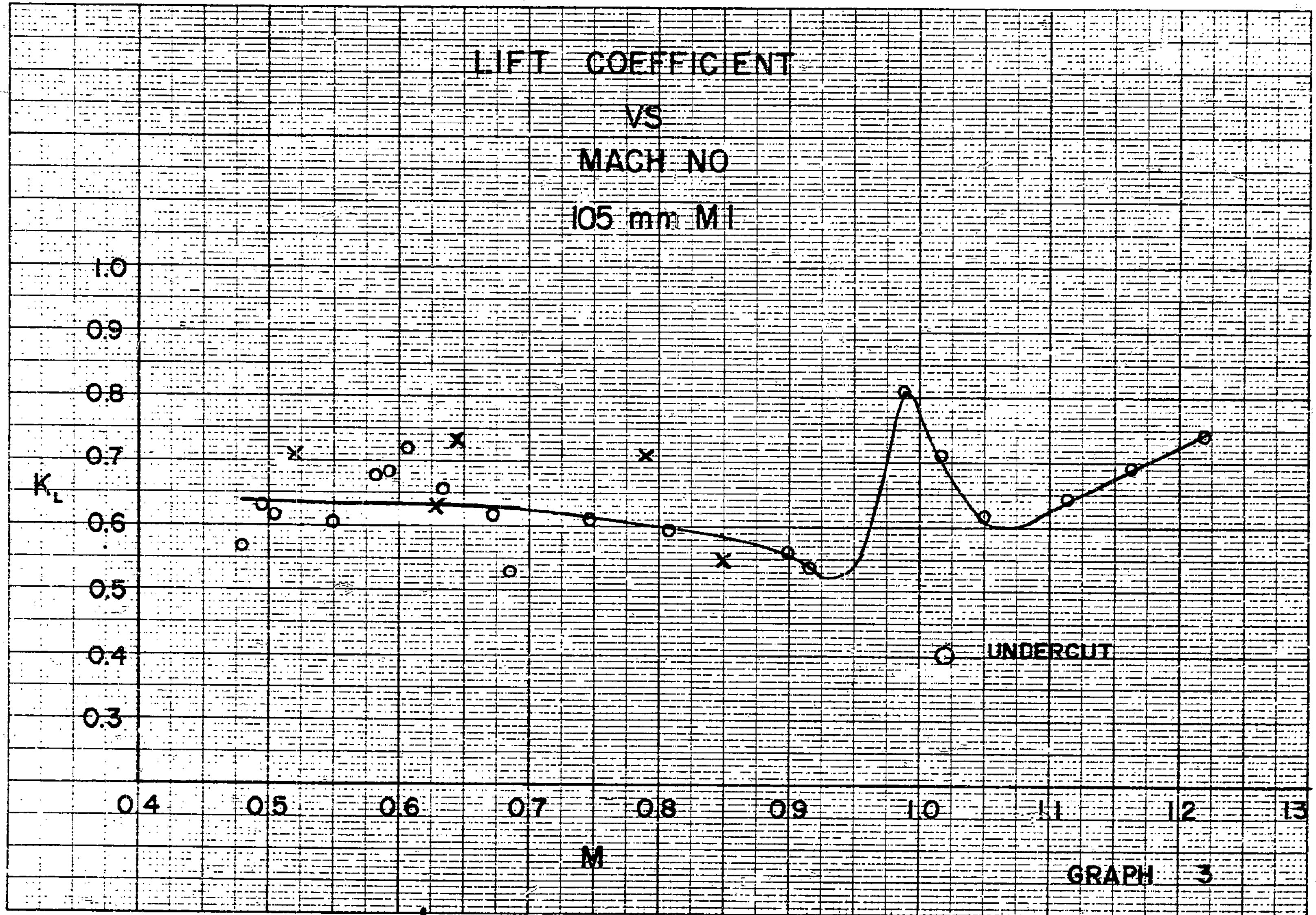
ϵ_{Yaw}	ϵ_{Swerve}
.002 rad	.009 ft

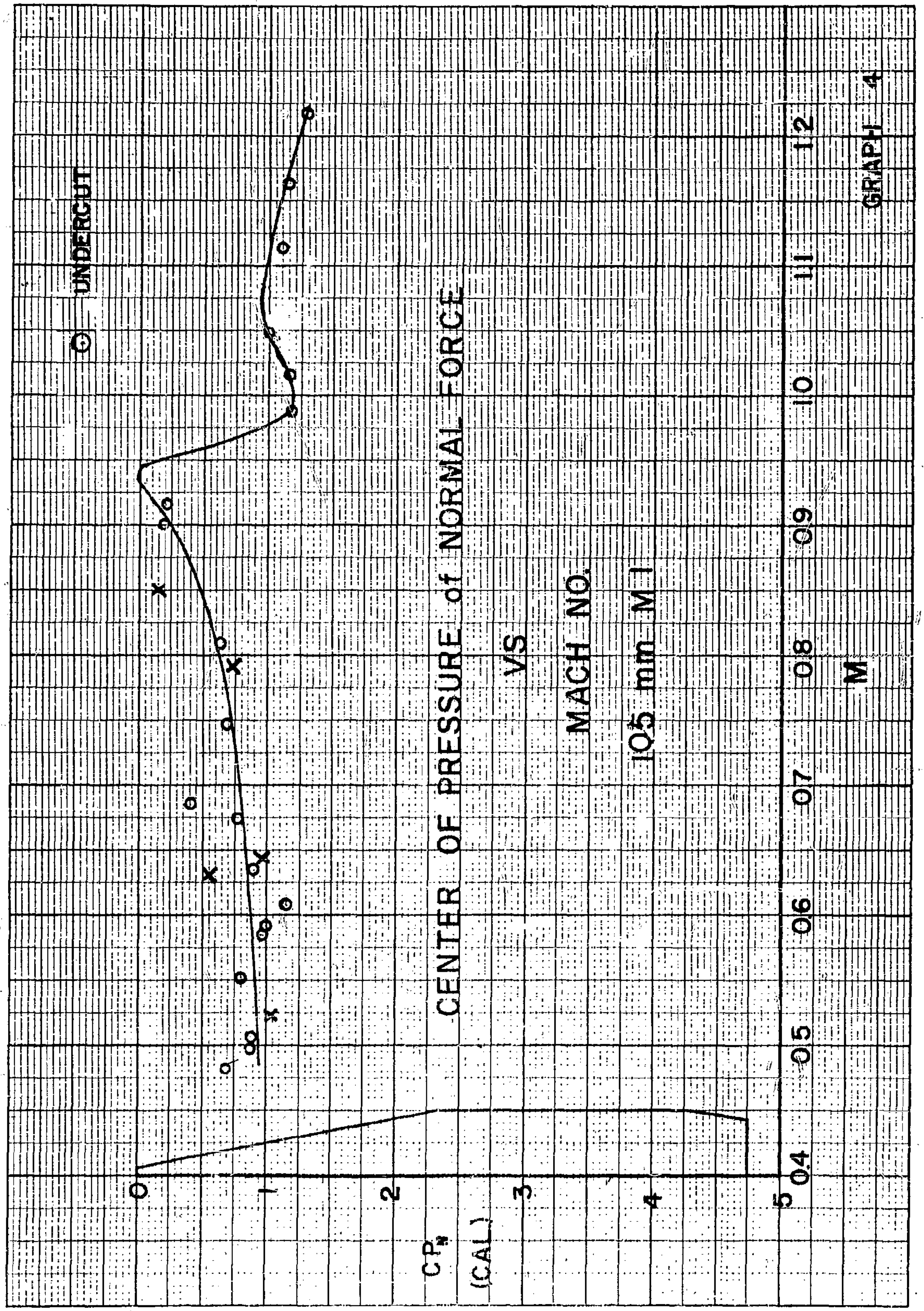
** Rounds 3191 - 3206 have not been undercut.

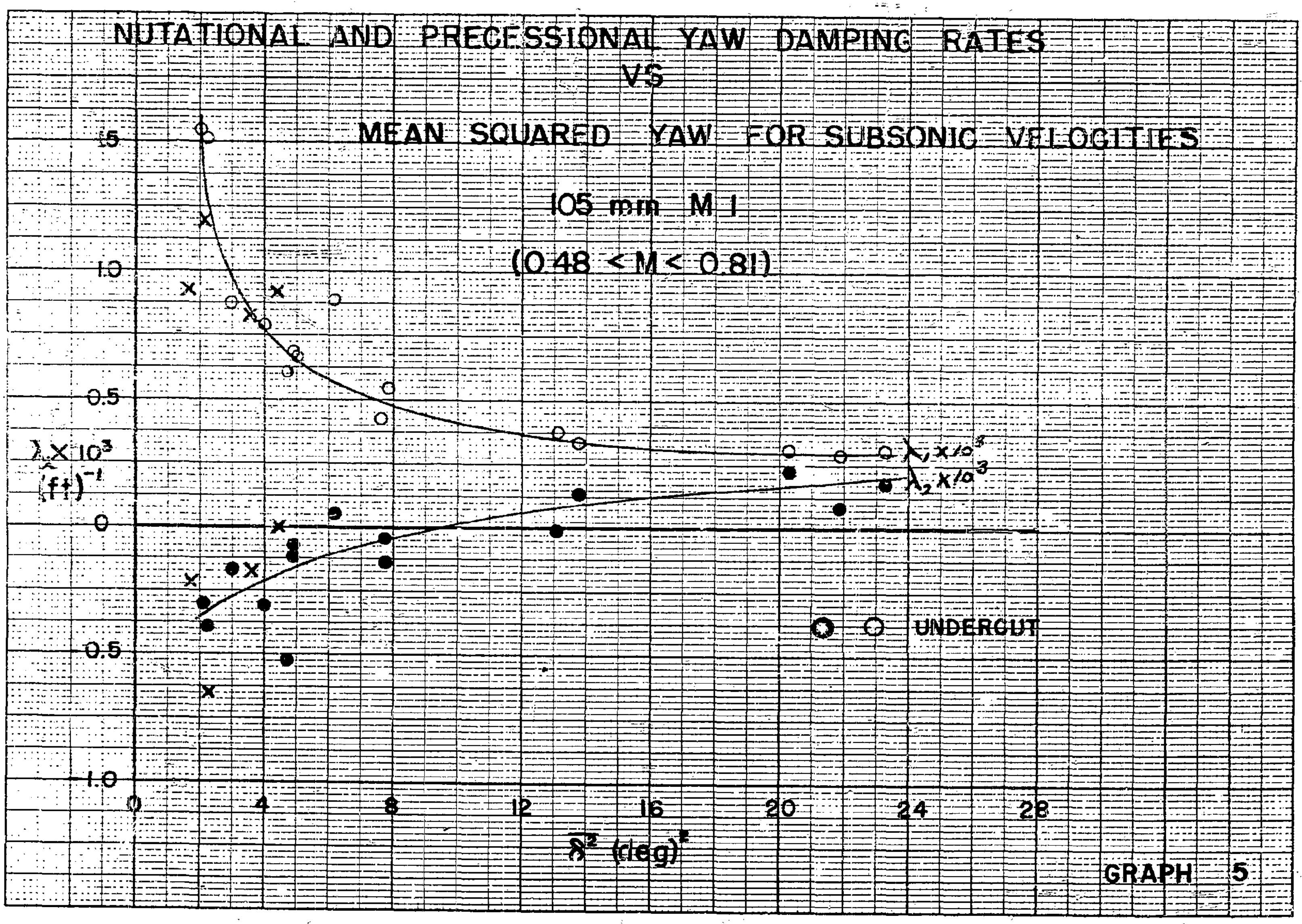

ZERO-YAW DRAG COEFFICIENT
VS
MACH NO.
105 mm M I
UNDERCUT
GRAPH 1
M
K_{D_0}
.4 .5 .6 .7 .8 .9 1.0 1.1 1.2
.04 .06 .08 .10 .12 .14 .16



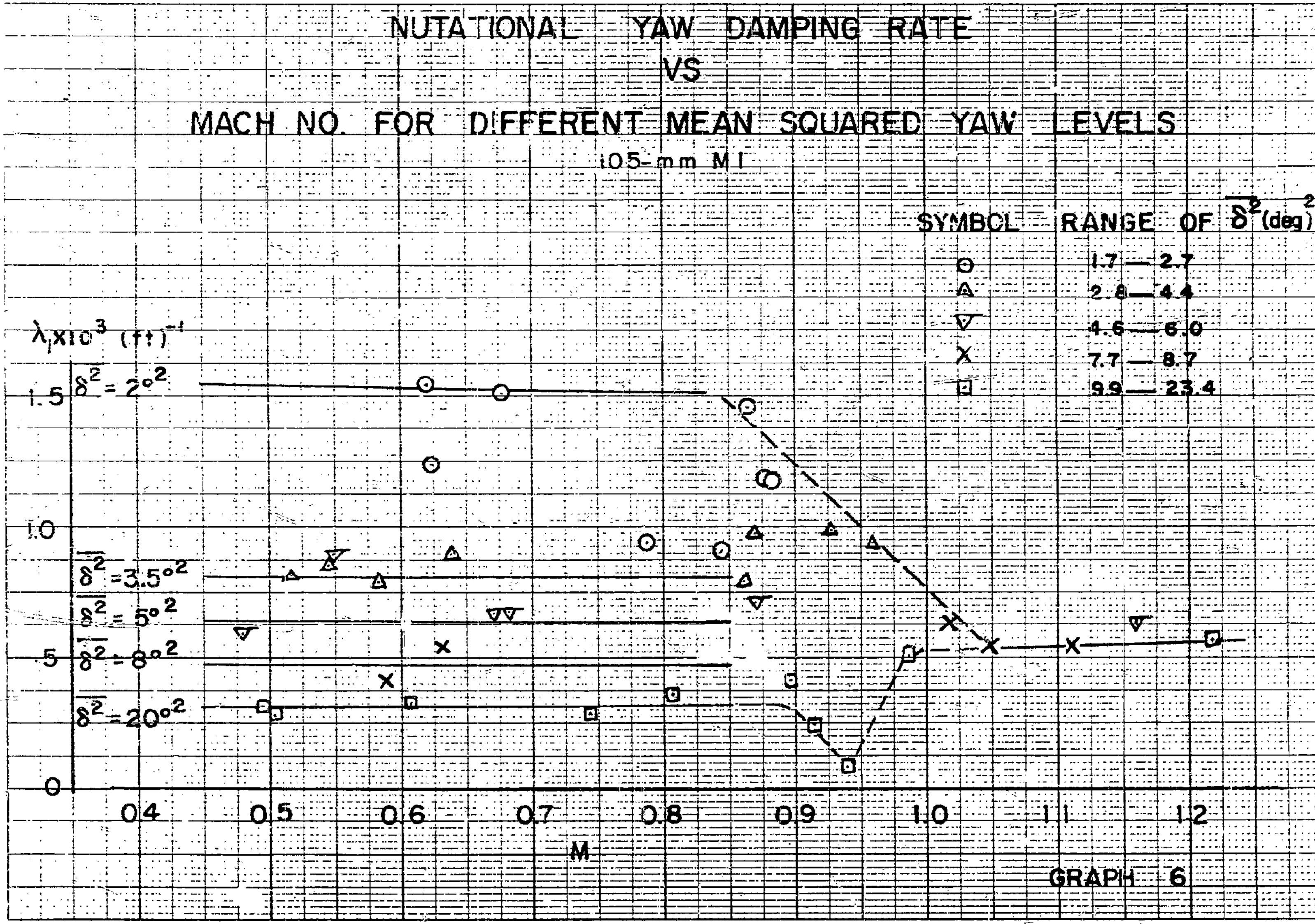
MOMENT COEFFICIENT
VS
MACH NO.
105 mm M1
UNDERCUT
GRAPH 2
MACH NO.
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
K_M
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3


LIFT COEFFICIENT
VS
MACH NO
105 mm M1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
K_L
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
M
UNDERCUT
GRAPH 3

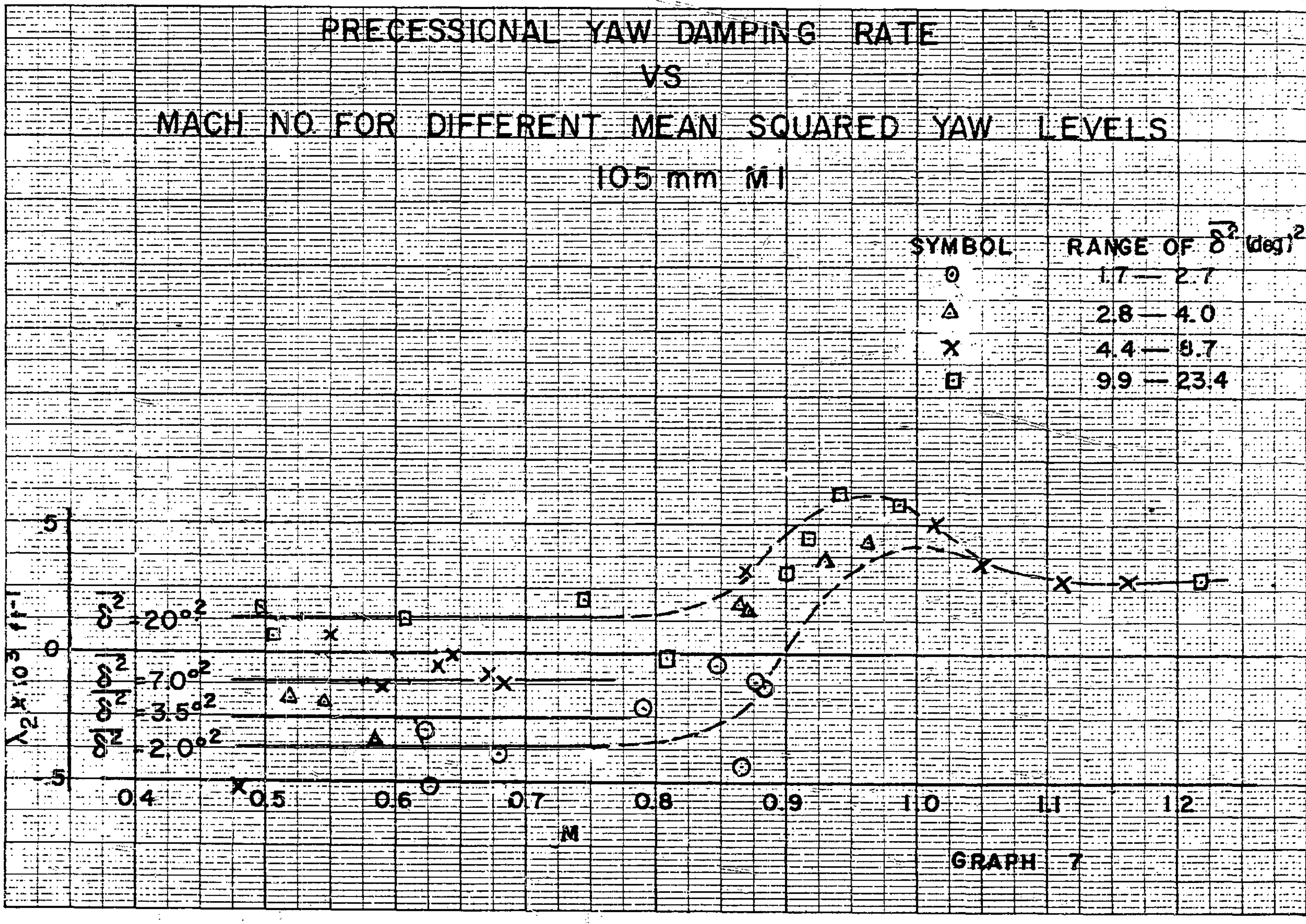

CENTER OF PRESSURE of NORMAL FORCE
VS
MACH NO.
105 mm M1
UNDERCUT
GRAPH 4
M
CP_N
(CAL)
0
1
2
3
4
5
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

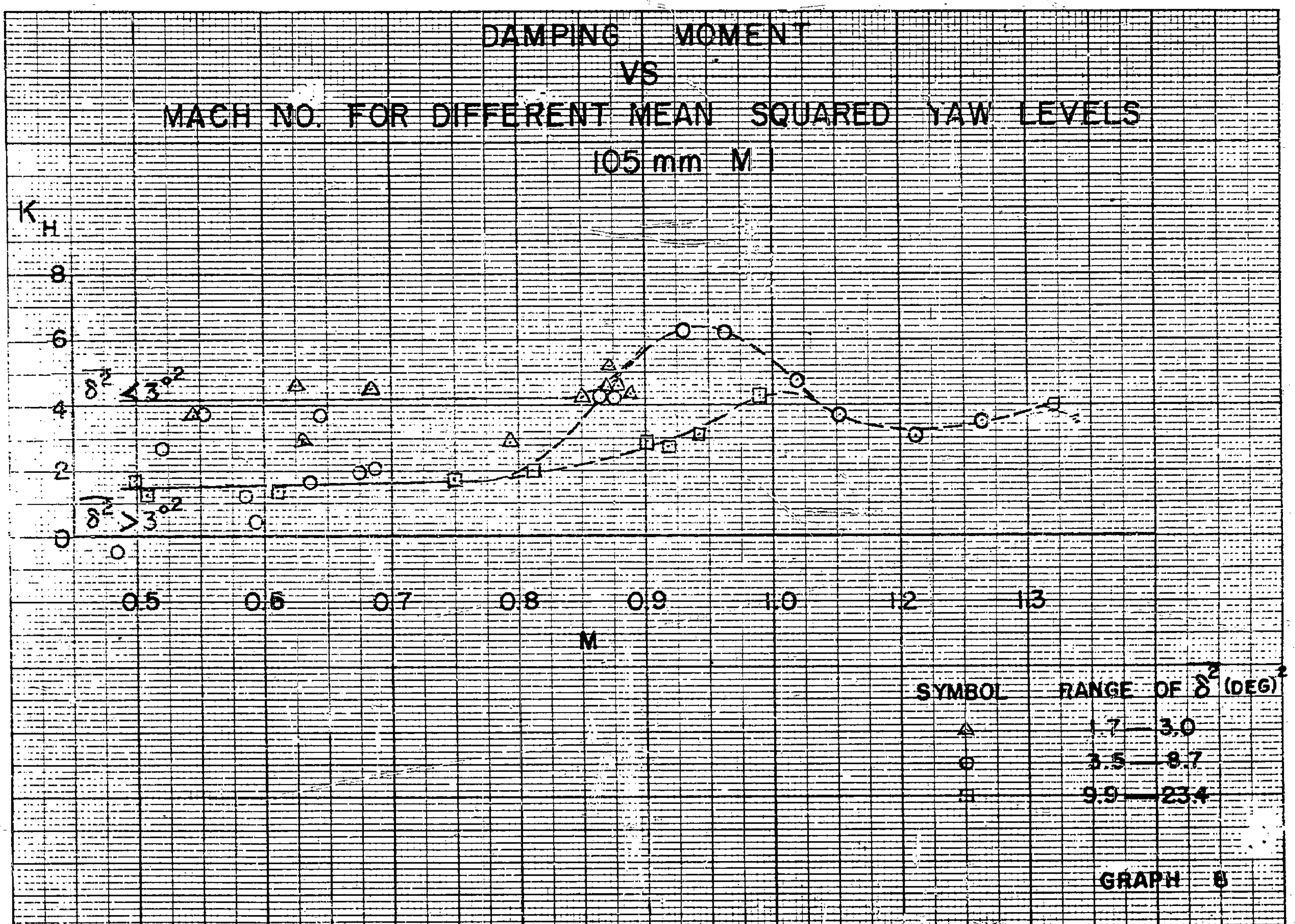


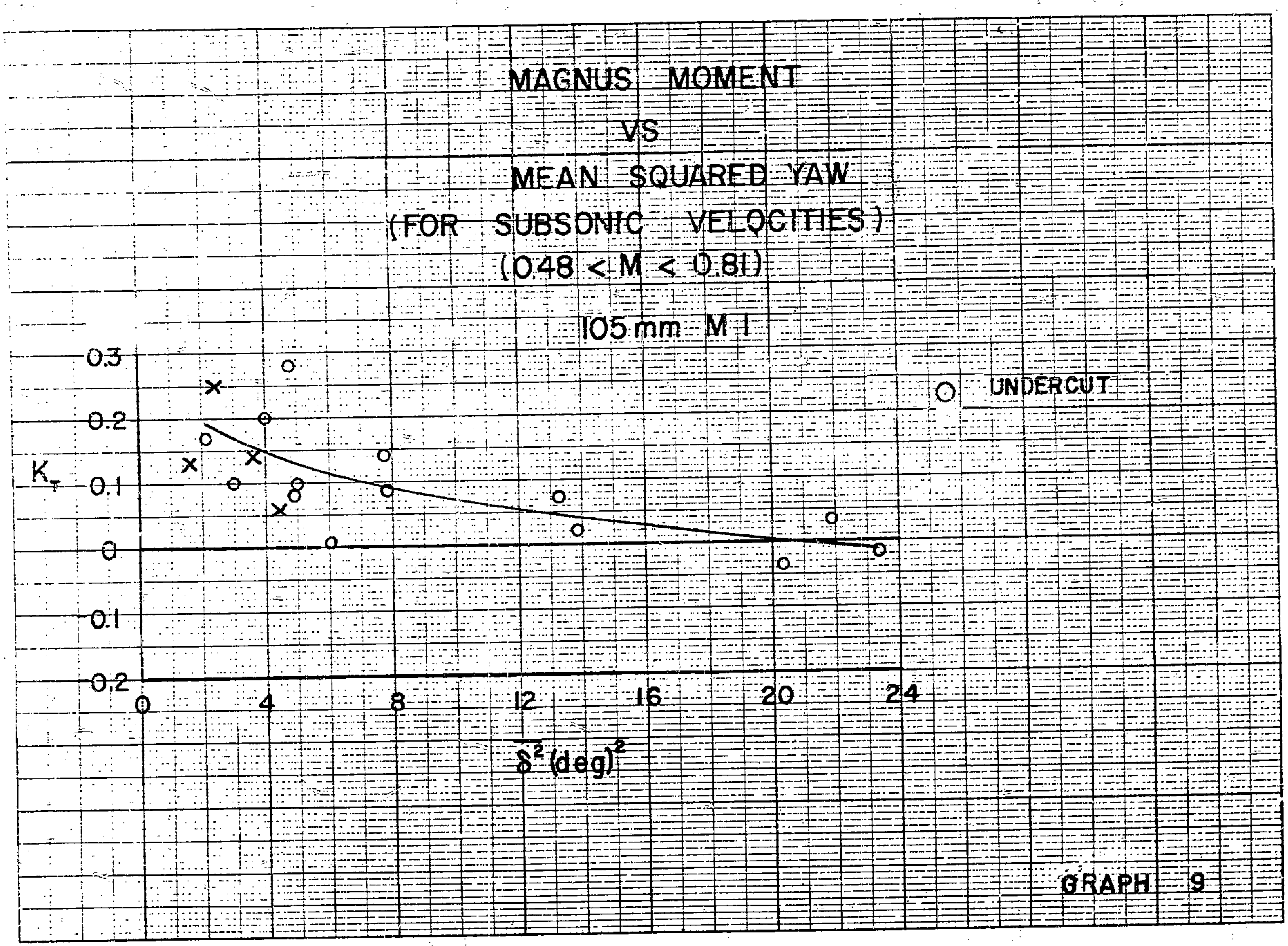
NUTATIONAL AND PRECESSIONAL YAW DAMPING RATES
VS
MEAN SQUARED YAW FOR SUBSONIC VELOCITIES
105 mm M 1
(0.48 < M < 0.81)
$\lambda \times 10^3$ $(ft)^{-1}$
1.5
1.0
0.5
0
0.5
1.0
0
4
8
12
16
20
24
28
$\overline{\delta^2}$ (deg)^2
$\lambda_1 \times 10^3$
$\lambda_2 \times 10^3$
UNDERCUT
GRAPH 5

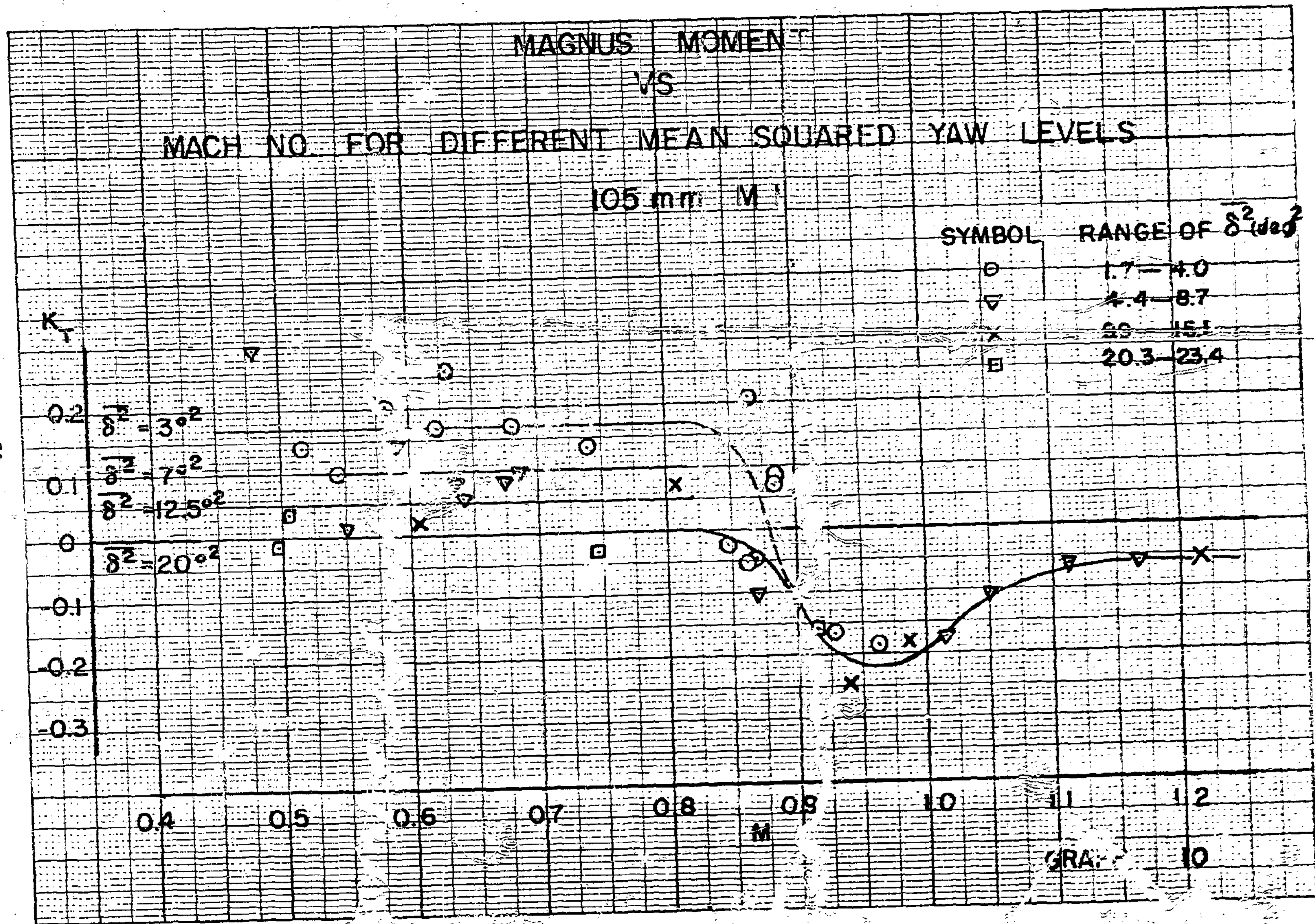


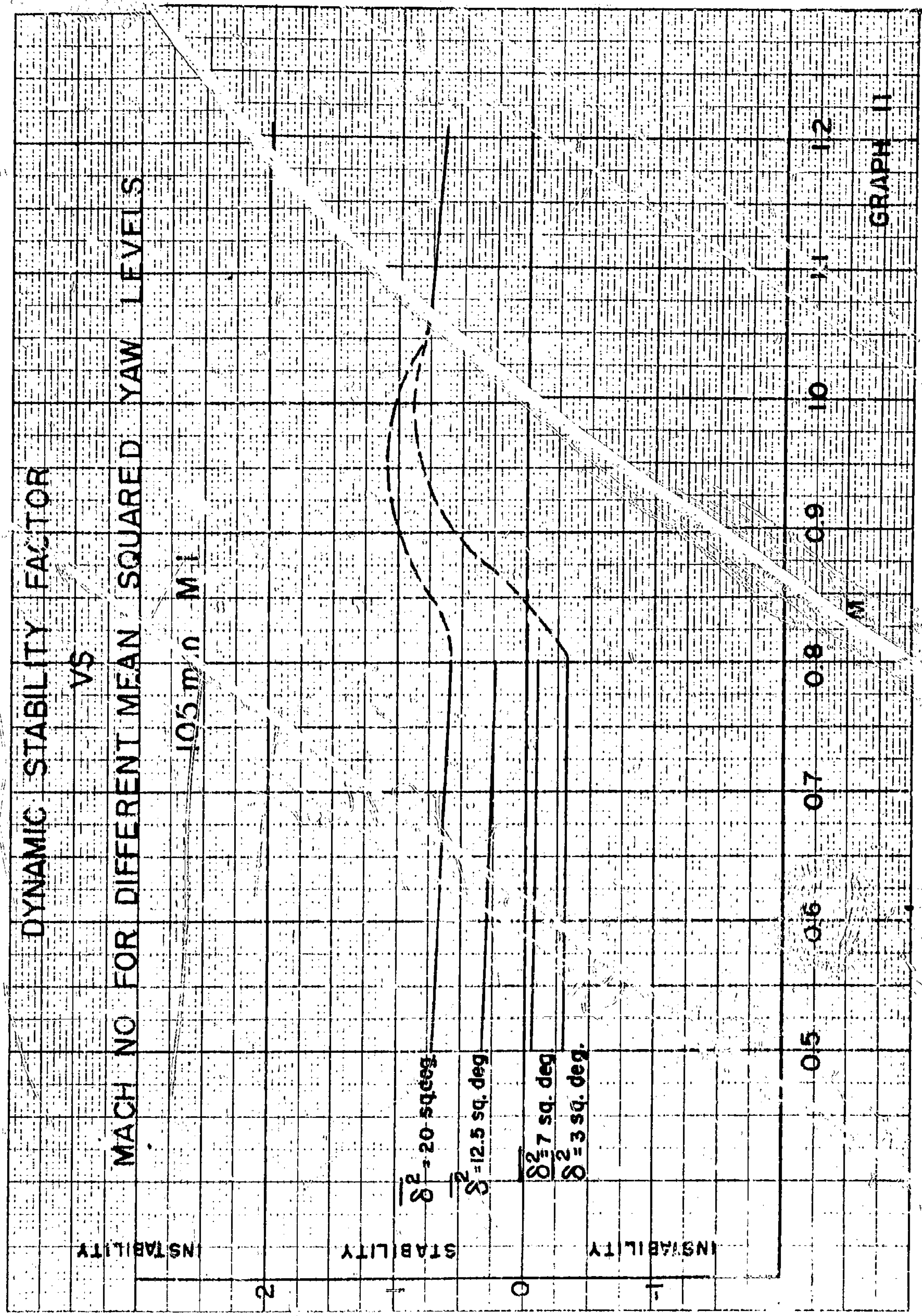
NUTATIONAL YAW DAMPING RATE
VS
MACH NO. FOR DIFFERENT MEAN SQUARED YAW LEVELS
105-mm M1
SYMBOL RANGE OF $\overline{\delta^2}$ (deg)^2
1.7 — 2.7
2.8 — 4.4
4.6 — 6.0
7.7 — 8.7
9.9 — 23.4
$\lambda_1 \times 10^3$ (ft)$^{-1}$
$\overline{\delta^2} = 2^{\circ 2}$
$\overline{\delta^2} = 3.5^{\circ 2}$
$\overline{\delta^2} = 5^{\circ 2}$
$\overline{\delta^2} = 8^{\circ 2}$
$\overline{\delta^2} = 20^{\circ 2}$
1.5
1.0
.5
0
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
M
GRAPH 6

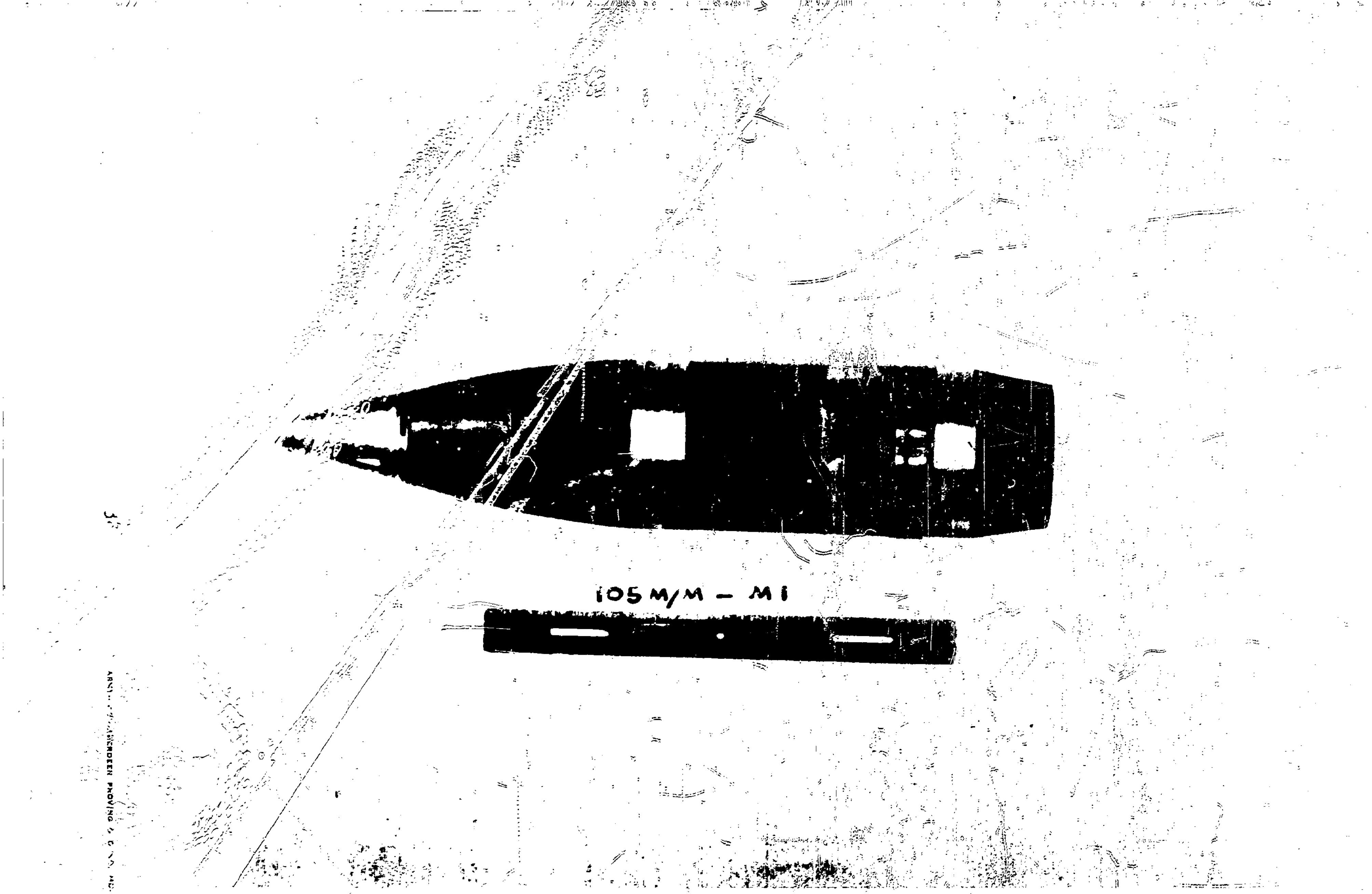

PRECESSIONAL YAW DAMPING RATE
VS
MACH NO FOR DIFFERENT MEAN SQUARED YAW LEVELS
105 mm M1
SYMBOL
RANGE OF $\overline{\delta^2}$ (deg)^2
1.7 — 2.7
2.8 — 4.0
4.4 — 8.7
9.9 — 23.4
$\overline{\delta^2} = 20^{\circ 2}$
$\overline{\delta^2} = 7.0^{\circ 2}$
$\overline{\delta^2} = 3.5^{\circ 2}$
$\overline{\delta^2} = 2.0^{\circ 2}$
$\lambda_2 \times 10^3$ ft^{-1}
5
0
-5
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
M
GRAPH 7


DAMPING MOMENT
VS
MACH NO. FOR DIFFERENT MEAN SQUARED YAW LEVELS
105 mm M1
K_H
8
6
4
2
0
$\overline{\delta^2} \leq 3^{\circ 2}$
$\overline{\delta^2} > 3^{\circ 2}$
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.3
M
SYMBOL
RANGE OF $\overline{\delta^2}$ (DEG)^2
1.7 — 3.0
3.5 — 8.7
9.9 — 23.4
GRAPH 8


MAGNUS MOMENT
VS
MEAN SQUARED YAW
(FOR SUBSONIC VELOCITIES)
(0.48 < M < 0.81)
105 mm M 1
UNDERCUT
K_T
0.3
0.2
0.1
0
0.1
0.2
0
4
8
12
16
20
24
$\overline{\delta^2}$ (deg)^2
GRAPH 9


MAGNUS MOMENT
VS
MACH NO. FOR DIFFERENT MEAN SQUARED YAW LEVELS
105 mm M1
SYMBOL
RANGE OF $\overline{\delta^2}$ (deg^2)
1.7 — 4.0
4.4 — 8.7
20.3 — 23.4
K_T
0.2
0.1
0
-0.1
-0.2
-0.3
$\overline{\delta^2} = 3^{\circ 2}$
$\overline{\delta^2} = 7^{\circ 2}$
$\overline{\delta^2} = 12.5^{\circ 2}$
$\overline{\delta^2} = 20^{\circ 2}$
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
M
10


DYNAMIC STABILITY FACTOR
VS
MACH NO FOR DIFFERENT MEAN SQUARED YAW LEVELS
105 mm M1
GRAPH 11
INSTABILITY
STABILITY
INSTABILITY
2
1
0
-1
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
M
$\overline{\delta^2}$ = 20 sq deg
$\overline{\delta^2}$ = 12.5 sq. deg
$\overline{\delta^2}$ = 7 sq. deg
$\overline{\delta^2}$ = 3 sq. deg.



APPENDIX C: Photograph of 105MM Shell, HE, M1

APPENDIX D: REFERENCES

(1) Schmidt, L. E., Aerodynamic Properties of 4.9 Calibers Long, Square Based Shell at Transonic Speeds, BRL Memorandum Report 824 (1954).

(2) Murphy, C. H., On the Stability Criteria of the Kelley-McShane Linearized Theory of Yawing Motion, BRL Report 853 (1953).

(3) Rogers, W. K., The Transonic Free Flight Range, BRL Report 849 (1953).

(4) Murphy, C. H., Data Reduction for the Free Flight Spark Ranges, BRL Report 900 (1954).

(5) McShane, E. J., Kelley, J. L., and Reno, F. V., Exterior Ballistics, University of Denver Press (1953).

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